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6           UNITED STATES PATENT APPLICATION  
7           FOR

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9           ENCODING SYSTEM

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## FIELD OF THE INVENTION

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4       The present invention relates generally to encoding systems and, for  
5 example, to encoding systems and methods for determining position and po-  
6 sition changes of a moving member and to printing devices with such encod-  
7 ing systems.

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## BACKGROUND OF THE INVENTION

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11       Encoding systems for sensing relative movements usually have a row of  
12 equidistantly spaced encoder marks attached to a first member and a sensor  
13 arrangement attached to a second member which is movable with relation to  
14 the first one. When the encoding marks move past the sensor arrangement  
15 signals according to the detected marks are generated. By counting the sig-  
16 nals, information regarding the position change between the two members  
17 (i.e. relative-position information) is obtained.

18       An example of such a system is a wheel with radial encoder marks  
19 mounted on a rotating axle, for example a pulley axle of a belt arrangement in  
20 an ink-jet printer. Each time a mark passes an (e.g. optical or magnetic) sen-  
21 sor, a signal is generated which indicates that the wheel has turned by one  
22 mark. Another example is a belt of an ink-jet printer equipped with a linear  
23 row of encoder marks. Each encoder signal indicates a belt advance of one  
24 mark. However, if all marks are identical, no absolute-position information is  
25 provided by such an encoder system.

26       In order to provide absolute-position information, it is known to equip an  
27 encoder with at least one index mark (or "reference mark"). Two types are  
28 known:

29       In double-channel (or multi-channel) encoders, the encoding marks and  
30 the reference mark are separately arranged and viewed by individual sensors  
31 (for example, US patent no. 5,206,645, Fig. 3).

32       In single-channel encoders, the different marks are arranged in one sin-  
33 gle encoder scale. Examples of such single-channel encoders are, for exam-

1 ple, described in US patents nos. 4,786,803, 4,789,874, 5,206,645 and  
2 5,411,340. In these single-channel encoders, the index mark is wider than the  
3 encoder marks, and in some of them one or more of the encoder marks are  
4 "hidden" by the index mark. The sensor generates different signals for the  
5 marks of different widths, which enables the two types of marks to be distin-  
6 guished. According to US patent no. 5,411,340, the virtual position of the hid-  
7 den encoder mark is estimated.

## SUMMARY OF THE INVENTION

A first aspect of the invention is directed to an encoding system for determining position and position changes of a moving member. According to the first aspect, the encoding system comprises a sequence of encoder marks forming incremental patterns and at least one index pattern, wherein two subsequent incremental patterns are indicative of an incremental-position-change of the moving member and the index pattern is indicative of a reference position of the moving member. The system further comprises a sensor arrangement viewing a section of the encoder-mark sequence, the length of which is greater than one position-change increment and an analyzer arranged to analyze an encoder-mark pattern in the viewed section with regard to the incremental patterns and the index pattern and to generate, in response to a pattern match found, at least one of an incremental-position-change signal and an index signal.

According to another aspect, an encoding system is provided for determining position and position changes of a moving member. The encoding system comprises a row of encoder marks arranged along the moving member in a generally regular manner to provide incremental-position-change information. The system further comprises at least one index marking in the form of a predefined pattern of encoder marks which represents a disturbance of the regular encoder-mark arrangement and a sensor arrangement viewing a section of the row of encoder marks and arranged to provide a viewed pattern of the encoder-mark section. The system further comprises an analyzer arranged to analyze the viewed pattern to generate incremental-

1 position-change signals on the basis of the encoder marks and an index sig-  
2 nal in response to a detection of the predefined index mark pattern. The in-  
3 cremental-position-change signals are also able to be generated also in that  
4 section of the encoder-mark row in which the regular encoder-mark arrange-  
5 ment is disturbed by the index marking.

6 According to another aspect, an encoding system is provided for deter-  
7 mining position and position changes of a moving member. The encoding  
8 system comprises a row of identical encoder marks forming incremental pat-  
9 terns and at least one index pattern, wherein two subsequent incremental  
10 patterns are indicative of an incremental position-change of the moving mem-  
11 ber and the index pattern is indicative of a reference position of the moving  
12 member. The system further comprises a sensor arrangement detecting a  
13 pattern of a section of the encoder-mark row and an analyzer arranged to  
14 analyze the detected encoder-mark pattern with regard to the incremental  
15 patterns and the index pattern and to generate, in response to an incre-  
16 mental-pattern match found, an incremental-position-change signal and, in  
17 response to an index-pattern match found, an index signal.

18 According to another aspect, a printing device is provided having an en-  
19 coding system for determining position and position changes of a moving re-  
20 cording medium conveyor to determine the position of a recording medium  
21 placed on the conveyor. The encoding system comprises a sequence of en-  
22 coder marks forming incremental patterns and at least one index pattern,  
23 wherein two subsequent incremental patterns are indicative of an incremental  
24 position-change of the moving member and the index pattern is indicative of a  
25 reference position of the moving member. The system further comprises a  
26 sensor arrangement viewing a section of the encoder-mark sequence, the  
27 length of which is greater than one position-change increment and an ana-  
28 lyzer arranged to analyze an encoder-mark pattern in the viewed section with  
29 regard to the incremental patterns and the index pattern and to generate, in  
30 response to a pattern match found, at least one of an incremental-position-  
31 change signal and an index signal.

32 According to another aspect, a printing device is provided having an en-  
33 coding system for determining position and position changes of a moving

1 member to determine the position of a recording medium placed on the con-  
2 veyor. The encoding system comprises a row of encoder marks arranged  
3 along the moving member in a generally regular manner to provide incre-  
4 mental-position-change information. The system further comprises at least  
5 one index marking in the form of a predefined pattern of encoder marks which  
6 represents a disturbance of the regular encoder-mark arrangement and a  
7 sensor arrangement viewing a section of the row of encoder marks and ar-  
8 ranged to provide a viewed pattern of the encoder-mark section. The system  
9 further comprises an analyzer arranged to analyze the viewed pattern to gen-  
10 erate incremental-position-change signals on the basis of the encoder marks  
11 and an index signal in response to a detection of the predefined index mark  
12 pattern. The incremental-position-change signals are enabled to be generated  
13 also in that section of the encoder-mark row in which the regular encoder-  
14 mark arrangement is disturbed by the index marking.

15 According to another aspect, a printing device is provided having an en-  
16 coding system for determining position and position changes of a moving  
17 member to determine the position of a recording medium placed on the con-  
18 veyor. The encoding system comprises a row of identical encoder marks  
19 forming incremental patterns and at least one index pattern, wherein two sub-  
20 sequent incremental patterns are indicative of an incremental position-change  
21 of the moving member and the index pattern is indicative of a reference posi-  
22 tion of the moving member. The system further comprises a sensor arrange-  
23 ment detecting a pattern of a section of the encoder-mark row and an ana-  
24 lyzer arranged to analyze the detected encoder-mark pattern with regard to  
25 the incremental patterns and the index pattern and to generate, in response  
26 to an incremental-pattern match found, an incremental-position-change signal  
27 and, in response to an index-pattern match found, an index signal.

28 According to another aspect, a method is provided of determining posi-  
29 tion and position changes of a moving member using a sequence of encoder  
30 marks which forms incremental patterns and at least one index pattern,  
31 wherein two subsequent incremental patterns are indicative of an incremental  
32 position-change of the moving member and the index pattern is indicative of a  
33 reference position of the moving member, comprising the steps: viewing a

1 section of the encoder-mark sequence, the length of which is greater than  
2 one position-change increment; analyzing an encoder-mark pattern in the  
3 viewed section with regard to the incremental patterns and the index pattern;  
4 and generating, in response to a pattern match found, at least one of an in-  
5 cremental-position-change signal and an index signal.

According to another aspect, a method is provided of determining position and position changes of a moving member using a row of encoder marks arranged along the moving member in a generally regular manner to provide incremental-position-change information; at least one index marking in the form of a predefined pattern of encoder marks which represents a disturbance of the regular encoder-mark arrangement, comprising the steps: viewing a section of the row of encoder marks; providing a viewed pattern of the encoder-mark section; analyzing the viewed pattern to generate incremental-position-change signals on the basis of the encoder marks and an index signal in response to a detection of the predefined index mark pattern. The incremental-position-change signals are enabled to be generated also in that section of the encoder-mark row in which the regular encoder-mark arrangement is disturbed by the index marking.

19 Other features are inherent in the methods and products disclosed or  
20 will become apparent to those skilled in the art from the following detailed de-  
21 scription of embodiments and its accompanying drawings.

## **DESCRIPTION OF THE DRAWINGS**

25 Embodiments of the invention will now be described, by way of example,  
26 and with reference to the accompanying drawings, in which:

27 Fig. 1 illustrates a linear-encoding system;  
28 Fig. 2 illustrates an angular encoding system;  
29 Fig. 3 schematically shows a sensor arrangement;  
30 Fig. 4 illustrates an exemplary index marking, a regular arrangement  
31 of encoding marks, and a regular arrangement disturbed by the index mark-  
32 ing:

Fig. 5 shows different possible viewed patterns, when the index

1 marking of Fig. 4 is used, and illustrates one embodiment of a pattern ana-  
2 lyzer arranged to generate incremental and index signals in dependence on  
3 the viewed pattern;

4 Fig. 6 shows a flow diagram of another embodiment of a pattern  
5 analyzer;

6 Fig. 7 illustrates a movement of an encoder mark with the index  
7 marking of Fig. 4 and 5 past a sensor arrangement;

8 Fig. 8 shows different viewed pattern and illustrates signal genera-  
9 tion similar to Fig. 5, but for another exemplary index marking;

10 Fig. 9 illustrates a printing device equipped with a linear-encoding  
11 system of Figs. 1, 2 to 8.

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#### 13 DESCRIPTION OF THE PREFERRED EMBODIMENTS

14

15 Figs. 1 and 2 illustrate linear and angular encoding systems. Before pro-  
16 ceeding further with the detailed description of Figs. 1 and 2, however, a few  
17 items of the embodiments will be discussed.

18 In the embodiments, the encoding system has encoder marks arranged  
19 in a sequence (or row) which are fixed to a moving member or a complemen-  
20 tary non-moving member. The encoder marks used in a particular embodi-  
21 ment are equal, and they are regularly (equidistantly) arranged (except for an  
22 index marking region, as will be explained below). A sensor arrangement  
23 views the encoder-mark row. Each time an encoder mark passes a sensor of  
24 the sensor arrangement, a signal is generated. At least in the region outside  
25 the index marking each signal of a particular sensor represents an advance of  
26 the moving member by one encoding mark distance. Accordingly, incremental  
27 counting of these signals, in principle, enables position changes of the moving  
28 member (or its "relative position") to be determined; the position change cor-  
29 responds to the encoding mark distance times the number of counted signals  
30 (actually, in the embodiments, the incremental position-change-signals are  
31 not simply based on individual sensor signals, but rather on certain combina-  
32 tions (or patterns) of signals from the different sensors of the sensor ar-  
33 rangement, as will be explained below).

1        In order to obtain an absolute position indication, an index (or reference)       
2 marking is also provided. It is indicative of a particular reference point on the       
3 (generally longitudinally extended) moving member, called "reference position". By       
4 starting the incremental counting at the index marking, i.e. by combining the       
5 absolute reference-position information of the index marking and the relative       
6 position information of the accumulated position-change signals, any position of the       
7 moving member can be absolutely determined.

8        In some of the preferred embodiments the encoding system has only       
9 one index marking to provide unambiguous absolute position information. If,       
10 however, index marking ambiguities can be resolved, two or more index       
11 markings may be provided; (for example, in a printer with several print stations       
12 equipped with sensors responsive to index markings, the ambiguity between a       
13 plurality of index markings can be effectively resolved if the distance between       
14 index markings is larger than the distance between the print stations).

16       In the preferred embodiments, the index marking is not arranged in a       
17 separate channel and has no mark with a shape different from the encoder       
18 marks. Rather, the index marking is a predefined pattern formed by equal encoder       
19 marks which can be considered as a disturbance of the regular encoder-mark       
20 arrangement. Consequently, the encoder-mark arrangement is strictly regular only       
21 in those regions of the encoder-mark row which are not disturbed by the index       
22 pattern; the entire arrangement (including the index marking) is called "generally regular".

24       The embodiments described enable relative position information (based       
25 on incremental signals) and absolute position information (based on index       
26 signals) to be obtained with a smaller relative error than in conventional systems       
27 which used different sensors or encoder marks of different shape or size to       
28 distinguish between incremental and index markings. In the embodiments, identical       
29 markings and one and the same sensor arrangement is used to detect both incremental       
30 and index markings which helps reduce possible systematic shifts between the relative       
31 and absolute position determination. Unlike systems with separate sensors for encoding and index marks, the relative       
32 error between the detected encoding marks and the index marking is zero or

1 negligible, and practically no systematic or random errors are present, in the  
2 embodiments. Accordingly, when the embodiments of the encoding system,  
3 for example, are used in printers, the image registration between different  
4 print stations and, consequently, the achievable image quality, may be im-  
5 proved.

6 The sensor arrangement views a section of the encoder-mark row. It is  
7 arranged to provide information representative of the pattern of the viewed  
8 encoder-mark section also called the viewed or detected pattern).

9 In the preferred embodiments, the sensor arrangement has a plurality of  
10 sensor elements which simultaneously view a plurality of fields of the en-  
11 coder-mark row, and, accordingly, can simultaneously detect a plurality of  
12 encoder marks in the viewed encoder-mark section.

13 In other embodiments the sensor arrangement has a sensor which suc-  
14 cessively detects individual encoder marks (or sub-sections) of the encoder-  
15 mark section upon a movement of the moving member. The encoding system  
16 combines the successively detected encoder marks to form a representation  
17 of the encoder-mark pattern in the section. Embodiments with successive de-  
18 tection of encoder marks are less preferred since the complete encoder-mark  
19 pattern is only obtained with a delay since a full pattern is only known when  
20 the last encoder mark of the section has been detected.

21 The length of the index pattern is chosen such that the encoder-mark  
22 pattern and the index pattern can be distinguished (i.e. the two patterns are  
23 orthogonal or quasi-orthogonal, even in the presence of noise (e.g. errone-  
24 ously detected or not detected marks)). In some of the embodiments, the  
25 length of the viewed encoder-mark section corresponds to the length of the  
26 index marking. However, if a unique identification of the index marking, even  
27 in the presence of noise, is already enabled by a part of the index marking, it  
28 may be sufficient to view only an encoder-mark section shorter than the  
29 length of the index marking. Conversely, to improve robustness against noise,  
30 in some embodiments the length of the viewed encoder-mark section is larger  
31 than the length of the index marking.

32 An analyzer receives the pattern information detected by the sensor ar-  
33 rangement. The analyzer is, for example, a digital processor which compares

1 viewed patterns with stored predetermined patterns and finds matches be-  
2 tween them. The analyzer may be a device especially dedicated to the pat-  
3 tern analysis. Alternatively, it may be part of another device, e.g. a controller  
4 of an apparatus (e.g. a printer) with which the encoding system is associated.  
5 For example, the analyzer may then be a process executed in the controller  
6 besides other processes. The analyzer generates encoder signals which indi-  
7 cate the incremental position-changes of the moving member on the basis of  
8 the encoder marks. Furthermore, it generates an index signal in response to a  
9 detection of the predefined index mark pattern.

10 In the embodiments, the sensor arrangement detects a multiplicity of  
11 encoder marks in the viewed section, although, in principle, one encoder  
12 mark would be sufficient to generate an encoder signal providing incremental  
13 position-change information. In other words, the detected multiplicity of en-  
14 coder marks carry redundant incremental position-change information at least  
15 in regions of regular encoder-mark arrangement (i.e. in regions in which the  
16 regular encoder-mark arrangement is not disturbed by the index marking).  
17 The disturbed region includes additional information, e.g. the index marking.  
18 Although this reduces or even takes away the redundancy of the incremental  
19 position-change information, sufficient incremental-position-change informa-  
20 tion is still included to enable incremental position-change signals to be gen-  
21 erated even in that part of the encoder-mark arrangement which is disturbed  
22 by the index marking.

23 Considering the index marking as a disturbance of a regular encoder-  
24 mark arrangement (as above) is one possible way to describe the encoding  
25 system of the embodiments. Another possible description treats the genera-  
26 tion of the incremental-position-change signals and the generation of the in-  
27 dex signal in an equal manner. In this alternative description, the encoder-  
28 mark row is considered to form incremental patterns and at least one index  
29 pattern. Two subsequent incremental patterns are indicative of an incremental  
30 position-change of the moving member. The index pattern is indicative of the  
31 moving member's absolute reference position. By definition, the incremental  
32 patterns and the index pattern may be considered to have equal lengths. In  
33 the embodiments, one unit of incremental position-change is smaller than the

1 length of the incremental pattern, which means that subsequent incremental  
2 patterns overlap. The section of the encoder-mark row viewed by the sensor  
3 arrangement is greater than one such position-change increment. Preferably,  
4 the length of the viewed encoder-mark section is equal to the length of the  
5 incremental patterns and the index pattern, but it may also be greater or  
6 smaller than that. The analyzer "knows" all predefined patterns (i.e. the in-  
7 cremental patterns and the index pattern) and generates, in response to an  
8 incremental-pattern match found, an incremental-position-change signal, and,  
9 in response to an index-pattern match found, an index signal.

10 In the embodiments, the encoder marks are identical. For example, if  
11 the encoding system is an optical system, the encoder marks have the same  
12 shape, size and color and the same orientation on the moving member. Ac-  
13 cordingly, the index mark is not defined by special marks, but by a special  
14 pattern of the identical encoder marks.

15 In some of the embodiments, the encoding system is an angular system  
16 in which the encoder marks are arranged in a circular row on a rotating mem-  
17 ber. In other embodiments the encoding system is linear; the encoder marks  
18 are arranged in a linear row parallel to the moving member's advance direc-  
19 tion; their orientation is typically perpendicular to the advance direction (but  
20 the marks may be inclined to the advance direction if lateral displacements of  
21 the moving member are also to be detected). Of course, the term "moving  
22 member" does not imply that the member is necessarily rigid. Rather, the  
23 member may be flexible, such as, for example, a conveying belt in a printer or  
24 a print medium (e.g. paper) on which the encoder marks are printed.

25 The described encoding system may, for example, be used in devices in  
26 which a moving member has to be accurately positioned (such as in robots)  
27 or the position of a moving member has to be accurately known (such as in  
28 printing scanning measurement devices). For example, in an embodiment of  
29 a printing device described below, the encoding system is used for determin-  
30 ing position (i.e. the absolute reference position) and position changes (i.e.  
31 the relative position) of a recording medium conveyor, which is, for example,  
32 a belt or drum conveyor. Preferably, the encoding system when used in a  
33 printing device will determine the position of a recording medium placed on

1 and moved by the conveyor. By measuring the recording medium's position  
2 relative to the conveyor by means of an additional sensor (e.g. a media pres-  
3 ence sensor) and assuming that the recording medium does not move rela-  
4 tive to the conveyor, a precise measurement of the conveyor's position and  
5 position changes is an indirect precise measurement of the recording me-  
6 dium's position and position changes. The sensor for example can be either  
7 placed in fixed position to sense the entire width of the medium in one read-  
8 ing or parked in a side position to sense the entire width of the medium in a  
9 scanning movement, by means of a motor, in a direction perpendicular to the  
10 medium advance direction. The row of encoder marks is arranged along the  
11 conveyor. The printing device is a multicolor printer with a plurality of page-  
12 wide print stations which extend over the recording medium conveyor and are  
13 spaced from one another in the advance direction. Each print station is indi-  
14 vidualy equipped with a sensor arrangement, and an analyzer of the kind de-  
15 scribed above is associated with each print station. The sensor arrangements  
16 view the same row of encoder marks, but, due to the spaced arrangement of  
17 the print stations, different sections of the encoder-mark row which are adja-  
18 cent to the respective print station. Such a print-station-individual measure-  
19 ment of the conveyor's relative and absolute position enables a precise regis-  
20 tration of the images printed by the spaced print stations onto each other,  
21 which improves the image quality. The improvement achieved by such a print-  
22 station-individual measurement is particularly advantageous with non-rigid  
23 conveyors, such as belt conveyors. For example, a belt may carry out oscilla-  
24 tory movements with a component in a direction perpendicular to the re-  
25 cording-medium-advance direction, and it may expand and shrink in the ad-  
26 vance direction (e.g. due to temperature changes), which could generally in-  
27 troduce registration errors between the print stations. The described print-  
28 station-individual measurement limits the amount of registration errors intro-  
29 duced between the print stations.

30       For certain applications, two orthogonal encoding systems of the kind  
31 described may be used. For example, in order to enable the absolute position  
32 of a movable tool on a two-dimensional surface (e.g. a table) to be deter-  
33 mined, two orthogonal edges of the table may be equipped with rows of en-

1 coding marks, each including an index marking, as described herein.

2       Returning now to Figs. 1 and 2, encoding systems 1, 1' trace position  
3 and position changes of a moving member 2, 2'. Fig. 1 illustrates a linear-  
4 encoding system, and Fig. 2 an angular encoding system. The moving mem-  
5 ber 2 of the linear system shown in Fig. 1 bears a linear row 3 composed of  
6 individual encoder marks 4. The encoder marks 4 are in the shape of short  
7 strokes or lines perpendicular to an advance direction of the moving member  
8 2 (indicated by arrow 5). All encoder marks 4 are equal, and the distances  
9 between them are also equal, except in a region of row 3 in which an index  
10 marking is located (in the index marking, one or more encoding marks may be  
11 missing or inserted between the normally spaced encoding marks). A section  
12 6 of the row 3 of encoder marks 4 is viewed by a sensor arrangement 7. The  
13 sensor arrangement 7 is mounted on a fixed structure, e.g. by a sensor sup-  
14 port 8. In other embodiments, the encoder-mark row is fixed, whereas the  
15 sensor arrangement is mounted on the moving member and is thus move-  
16 able. Sensor output data is transferred to an analyzer 9 via a connection 10.  
17 Functional components of the analyzer 9 are a sensor input component 11, a  
18 comparator 12, a pattern memory 13, and a signal generator 14. The pattern  
19 memory 13 stores representations of predefined patterns of encoder marks 4  
20 as well as pattern attributes which indicate whether a stored pattern repre-  
21 sents an incremental pattern or an index pattern. The sensor output data is  
22 input via the input component 11. The comparator 12 compares the detected  
23 pattern of encoder marks 4 with all stored patterns. If it finds a match between  
24 the detected pattern and one of the stored patterns, it causes the signal gen-  
25 erator 13 to generate an incremental-position-change signal 15 or an index  
26 signal 16, if the attribute of the matching stored pattern indicates that it is an  
27 incremental pattern or an index pattern.

28       In the angular encoder 1' of Fig. 2 the moving member is a rotating disk.  
29 Correspondingly, the advance direction illustrated by arrow 5' is a section of a  
30 circular line. The encoder marks 3' are arranged on the flat front of the rotat-  
31 ing member 2', and are radially oriented. The sensor arrangement 7' is ar-  
32 ranged to view the radially oriented encoder marks 3' on the face of the rotat-  
33 ing member 2'. Regarding the analyzer 9, and the signals 15, 16 generated by

1 it, reference is made to the analyzer's description made above in connection  
2 with Fig. 1.

3 Fig. 3 illustrates an embodiment of the sensor arrangement 7 arranged  
4 to observe the section 6 of the row 3 of encoder marks 4. The sensor ar-  
5 rangement 7 has a plurality of individual sensor elements 18, each of which  
6 views a different field of row 3. The sensor elements 18, for example, are op-  
7 tical sensors indicative of the presence or absence of an encoder mark 4  
8 within the respective viewed field. The pitch of the sensor elements 18 corre-  
9 sponds to the pitch of the encoder marks 4 (wherein in the regions of regular  
10 encoder-mark arrangement each encoder mark is followed by a blank space;  
11 accordingly, only every second sensor element 18 will see an encoder mark,  
12 as explained in connection with Figs. 4 and 5 below). Furthermore, the size  
13 and orientation of the sensor elements 18 correspond to the ones of the en-  
14 coder marks 4. Accordingly, the sensor arrangement 7 is adapted to the en-  
15 coder-mark row 3 to detect patterns of encoder marks 4. The encoder marks  
16 4 will gradually move into and out of the encoder-mark area viewed by each  
17 sensor element 18. A signal preprocessor 19 differentiates the sensor signals  
18 and performs suitable signal processing in order to provide only one signal  
19 when an encoder bar has moved into the respective viewed field and to de-  
20 fine when this signal is triggered during this gradual movement (for example,  
21 the signal is triggered when the encoding mark and the field are coincident).  
22 Further, it combines the processed signals and forwards them to the analyzer  
23 9 via line 10. In the example shown in Fig. 3, the sensor arrangement 7 has  
24 ten sensor elements 18. The exemplary encoder-mark row 3 shown in Fig. 3  
25 is shown in such a position in which an index marking disturbing the regular  
26 arrangement of encoder marks 4 is viewed by the sensor arrangement 7, as  
27 will be explained in connection with Fig. 4.

28 Fig. 4a illustrates an incremental-encoder-mark unit 20 composed of an  
29 encoder mark 4 and a blank space 21. The encoder mark 4 and the blank  
30 space 21 are represented by "1" and "0", respectively. Fig. 4c illustrates a  
31 regular sequence of such units 20. This regular sequence is present in the  
32 row 3 of encoder bars 4 outside the region which bears the index marking.  
33 The period of this regular sequence (i.e. the distance between the center of

1 two consecutive encoder marks 4) corresponds to one incremental position-  
2 change of the moving member. Incremental positions assigned to the incre-  
3 mental encoder-mark units 20 are also shown in Fig. 4c (denoted by "22"). A  
4 conventional encoder with a sensor which views and processes only single  
5 encoder marks would provide an incremental-position-change signal each  
6 time the center of an encoder mark (i.e. an incremental position 22 in Fig. 4c)  
7 passes by the sensor.

8 Fig. 4b illustrates an exemplary index marking 23. It has a length of  
9 eleven elements; it starts with three blank spaces 21, followed by five index  
10 markings 4, and is terminated by three blank spaces 21. Although the index  
11 marking 23 is a longitudinally extended object (longitudinally means "in the  
12 advance direction"), the moving member's reference position 24, which is in-  
13 dicated by the index marking, is, for example, at the center of the position of  
14 the leftmost of the three blank spaces 21 in Fig. 4b.

15 Fig. 4d illustrates that the index marking 23 is "embedded" in the regular  
16 arrangement of encoding marks 4 and blank spaces 21 of Fig. 4c. As can be  
17 seen, the regular arrangement is disturbed by the index marking 23. In the  
18 example of Fig. 4d, two encoding marks of the regular arrangement are re-  
19 moved (thereby forming the two blank-space triples) and two blank spaces of  
20 the regular arrangement are filled by encoder marks (thereby forming the five  
21 adjacent encoder marks). Also indicated in Fig. 4d is the reference-position  
22 24 of the index marking and incremental positions 22. The latter can be re-  
23 constructed although two encoder marks 4 have been replaced by blank  
24 spaces 21 and two blank spaces 21 by encoder marks 4, as will be explained  
25 in connection with Fig. 5 below.

26 Incidentally, what is precisely considered as the "index marking" is a  
27 matter of definition: for example, as can be seen in Fig. 4d, a possible differ-  
28 ent definition might exclude the third blank space 21 at the right-hand side of  
29 the index marking 23 in Fig. 4d.

30 In other embodiments, the index marking is only formed by missing en-  
31 coder marks, but no additional marks are inserted between the regularly ar-  
32 ranged encoder marks, as in Figs. 4b and 4d. In such embodiments, blank  
33 spaces may not be used to describe the incremental patterns and the index

1 pattern, and sensor elements for viewing blank spaces in the regular ar-  
2 rangement may not be provided.

3 Fig. 5 illustrates the pattern-analysis operation and signal generation  
4 performed by the analyzer 9 (Figs. 1 and 2). On the left-hand side of Fig. 5, all  
5 possible patterns are listed which may occur in the viewed section when the  
6 encoder-mark row of Figs. 4c and 4d with the exemplary index marking 23 is  
7 moved past the sensor arrangement. There are, in total, twenty-one different  
8 possible patterns. The right-hand side of Fig. 5 is a Boolean operation table  
9 which maps the possible twenty-one patterns to a certain incremental and  
10 index signal output (wherein "0" indicates "no signal", and "1" indicates a  
11 "signal"). The patterns P1 and P2 are the regular patterns which appear when  
12 the regular part of the encoder-mark row is shifted past the sensor arrange-  
13 ment. If the first viewed field (i.e. the rightmost in Fig. 5) is an index mark, an  
14 incremental signal is generated, but if it is a blank space, no incremental sig-  
15 nal is generated. The other patterns, P3 to P21 are irregular patterns which  
16 are detected by the sensor arrangement when the index marking of Fig. 4b is  
17 moved, field by field, into, and out of, the section viewed by the sensor ar-  
18 rangement. An incremental signal is generated every second pattern. When  
19 the index marking is completely within the viewed section (pattern P12), an  
20 index signal is generated. A further movement of the index mark row causes  
21 the index mark pattern to leave the viewed section (pattern P21), until the  
22 regular pattern P2 is observed again. In all cases except P12 no index signal  
23 is generated.

24 As can be seen in Fig. 5, the incremental-position-change information is  
25 redundantly contained in the regular patterns P1 and P2. In order to obtain  
26 the incremental-position-change information it would be sufficient to view only  
27 one field of the encoder-mark row. However, the use of a sensor arrangement  
28 viewing more fields enables the incremental signal to be generated even in  
29 that region of the encoder-mark row which is disturbed by the index marking  
30 (patterns P3 to P21). For example, if a sensor viewing only the first (right-  
31 most) field were used, no incremental signal would erroneously be generated  
32 for patterns P13 and P21 (although an incremental signal is due for these  
33 patterns), and erroneous incremental signals would be generated for patterns

1 P16 and P18. Thus, viewing a pattern with a multiplicity of encoder marks and  
2 analyzing the observed pattern as to whether it matches one of the prede-  
3 fined incremental patterns, rather than viewing only one encoding mark, en-  
4 ables the incremental-position-change information to be reconstructed even  
5 from that region in which the regular arrangement is disturbed by the index  
6 marking. Incidentally, it is clear from Fig. 5 that the incremental patterns over-  
7 lap since the pattern length is eleven fields, whereas the distance between  
8 incremental positions 24 (Fig. 4) only corresponds to two fields.

9 The pattern processing and signal generation illustrated in Fig. 5 is, for  
10 example, implemented in the analyzer as follows: the 20 different possible  
11 patterns P1 to P21 are stored in the pattern memory 13 (Fig. 1) together with  
12 the attributes indicating whether an incremental signal and/or an index signal  
13 is to be generated for the respective pattern. The comparator 12 (Fig. 2)  
14 compares a detected pattern with all stored patterns and tries to find that  
15 stored pattern which matches the detected pattern. Depending on the signal  
16 attribute of the matching pattern found, the signal generator 14 (Fig. 1) gen-  
17 erates no signal, an incremental signal or an index signal (or both of them,  
18 see Fig. 8 below).

19 Fig. 5 illustrates an ideal case without pattern errors or detection errors.  
20 In practice, however, pattern and detection errors may occur, for example, if  
21 the row of encoder marks is contaminated by ink, or if a mark is erroneously  
22 detected due to noise. Then, other ("incorrect") patterns than ones shown in  
23 Fig. 5 may also be output by the sensor arrangement. In order to cope with  
24 such erroneous detections, that pattern of the set of "correct" patterns shown  
25 in Fig. 5 is assigned to a detected "incorrect" pattern which is closest to the  
26 detected pattern. In some embodiments, the closest "correct" pattern is found  
27 by a maximum likelihood estimation.

28 Fig. 6 shows a flow diagram of another embodiment of a pattern ana-  
29 lyzer, based on calculating correlations between patterns. In block B1, a  
30 viewed pattern is received at the pattern analyzer. In block B2', the viewed  
31 pattern is correlated with the encoder pattern, which is "10101010101" in this  
32 example. "Correlating" means counting the number of same digits; therefore  
33 the correlation may go from 0 to 11. In block B2", the viewed pattern is corre-

1 lated with the index pattern, which is "00011111000" in this example. In block  
2 B3' it is ascertained whether the correlation of the viewed pattern with the en-  
3 coder pattern is higher than a certain threshold ("5" in the example of Fig. 6).  
4 If the outcome is positive an incremental signal is generated, if, however, it is  
5 negative, no incremental signal is generated (block B4'). In block B3" it is as-  
6 cerned whether the correlation of the viewed pattern with the index pattern  
7 is higher than a certain other threshold ("9" in the example of Fig. 6). If the  
8 outcome is positive an index signal is generated, if, however, it is negative, no  
9 index signal is generated (block B4"). By appropriately choosing the thresh-  
10 olds, robustness against noise may be optimized . For example, if the index-  
11 pattern correlation threshold is set to 10, only correct readings of the index  
12 pattern cause the generation of an index signal. If it is set to a value smaller  
13 than 9, a wrong index signal generation may occur if one "1" of the index pat-  
14 tern is read as a "0". The robustness against noise may be increased by view-  
15 ing a longer section of the row of encoder marks (for example 13 encoder  
16 marks, instead of the 11 marks shown in Fig. 6). The encoder-pattern corre-  
17 lation threshold is generally set to a smaller value, as illustrated in Fig. 6, since  
18 for a symmetric noise distribution, half of the length of the viewed encoder  
19 pattern is the optimal threshold. In case the noise distribution is not symmetri-  
20 cal, the optimal threshold would be higher or lower.

21 Fig. 7 illustrates how the encoder-mark row 3 of Fig. 4d is moved  
22 through the "window" of the sensor arrangement. Four different "snapshots"  
23 are shown, the viewed sections 6 of which correspond to patterns P1, P2, P5  
24 and P12 of Fig. 5. As defined by the Boolean operation table of Fig. 5, incre-  
25 mental signals 15 are generated when the patterns P1 and P5 are moved into  
26 the sensor arrangement's window, and an index signal is generated when the  
27 pattern P12 is moved into it.

28 Fig. 8 illustrates a pattern analysis and signal generation analogous to  
29 Fig. 5, but for another example of an index marking denoted by 23'. The index  
30 marking 23' has a length of six elements, it is composed of three encoder  
31 marks 4, followed by three blank spaces 21. Eleven different patterns, de-  
32 noted by R1 to R11 in Fig. 8, can be observed when a regular arrangement  
33 (as shown in Fig. 4c) is overlaid with the index marking 23', and when such an

1 encoder-mark row is moved past the detector arrangement (which, in this ex-  
2 ample, views only six elements). The pattern processing and signal genera-  
3 tion corresponds to what has been described in connection with Fig. 5, which  
4 illustrates that it is independent of the particular pattern chosen for the index  
5 marking. Incidentally, one difference due to the different pattern chosen can  
6 be seen in pattern R7: both the incremental signal and the index signal are  
7 generated for pattern R7, whereas only the index signal, but no incremental  
8 signal is generated for the corresponding pattern P12 of Fig. 5.

9       Fig. 9 illustrates a printing device 30 equipped with the linear-encoding  
10 system 1 of Figs. 1, 3 to 7. The printing device 30 is a multicolor printer with  
11 separate print bars 31 for the different colors to be printed (for example, cyan,  
12 magenta, yellow and black). The print bars 31 extend over the full width of a  
13 print medium 32, for example paper sheets (an already printed multicolor im-  
14 age is shown at 33 in Fig. 9). The exemplary printer of Fig. 9 is an ink-jet  
15 printer; other embodiments use other printing technologies, such as laser  
16 printing, dye sublimation printing, thermal way printing, solid ink printing, etc.

17       The multicolor image to be printed is virtually separated into single-color  
18 images to be printed by the respective single-color print bars 31 (some em-  
19 bodiments have redundant print bars, for example, two print bars for each  
20 color; in these embodiments, the single-color image to be printed is subdi-  
21 vided between the print bars of the same color, for example, by use of appro-  
22 priate print masks; other embodiments even have multicolor print bars). In  
23 order to achieve high image quality, the individual single-color images are  
24 printed onto the recording medium 32 onto each other in an aligned manner,  
25 which is also called "registering" the images. Since the print bars 31 are  
26 spaced in the recording-medium-advance direction 5, the different single-  
27 color images are printed one after the other, and the downstream print bars  
28 need to "know" where the first print bar printed its image onto the recording  
29 medium 32 in order to achieve precise image registration. This is accom-  
30 plished by the encoding system described above.

31       The printing device 30 has a moving member 2 in the form of a convey-  
32 ing belt guided by rollers 34, at least one of which is driven (in other embodi-  
33 ments, the moving member is a rotating drum). The row 3 of encoder marks 4

1 is arranged at one edge of the belt and parallel to it. The encoder marks 4  
2 are, for example, printed onto the belt or a strip attached to the belt (or the  
3 drum). The encoder marks 4 are oriented perpendicular to the advance direc-  
4 tion 5 and are regularly arranged. An index marking 23 forms a disturbance of  
5 their regular arrangement, as described above. Each print bar 31 is equipped  
6 with an individual sensor arrangement 7 which views a section of the en-  
7 coder-mark row 3 to provide print-bar-individual information about the relative  
8 and absolute belt position. This information is used to individually register the  
9 images printed by the print bars 31. A controller 35 controls the print activity  
10 of individual dot-forming elements (e.g. ink nozzles in an ink-jet printer) of the  
11 print bars 31 to print the required image. The controller 35 controls the print  
12 activity such that each of the print bars 31 downstream of the first print bar 31  
13 prints its image in a registered manner onto the first print bar's image. An  
14 analyzer 9 of the kind described above is provided for each print bar 31. The  
15 analyzers 9 are components of the controller 35; they are, for example, im-  
16 plemented as analyzer processes executed by the controller 35 simultane-  
17 ously with other processes (e.g. the process controlling the nozzle activity).  
18 The signals representing encoder marks detected by the sensor arrange-  
19 ments 7 are input to the controller 35, and the analyzers 9 generate the in-  
20 cremental and index signals for each print bar 31 based on these sensor sig-  
21 nals, as described above. In other embodiments, the print bars 31 are  
22 equipped with individual analyzer devices or a common analyzer device dedi-  
23 cated to process the detected encoder-mark patterns and generate the print-  
24 bar-individual incremental and index signals which are supplied to the control-  
25 ler 35.

26 The index and incremental signals are, for example, used to register the  
27 print bar's images in the following way: an incremental counter is assigned to  
28 each print bar. When the index marking 23 moves past a print bar 31 and is  
29 detected by the print bar's sensor arrangement 7 so that an index signal is  
30 generated for this print bar, the print bar's incremental counter is set to a ref-  
31 erence value (for example to "0"). Each incremental signal due to a subse-  
32 quent detection of an incremental pattern at this print bar causes the print  
33 bar's incremental counter to be incremented. Accordingly, the current content

1 of each of the counters represents the current position of the belt (and, con-  
2 sequently, of the recording medium 32 on the belt; it is assumed that the re-  
3 cording medium does not move relative to the belt which is a reasonable as-  
4 sumption in many applications) relative to a common reference point (i.e. the  
5 reference position of the index marking 23). When the first print bar 31 starts  
6 printing its image onto the recording medium 32 at a certain count of its asso-  
7 ciated incremental counter, the controller 35 controls the print action of the  
8 subsequent print bars 31 such that they also start to print their respective im-  
9 age when the same count is reached in their respective incremental counter.  
10 In this way, registration of the different images to be printed is accomplished.

11 The embodiments described enable relative position information (based  
12 on incremental signals) and absolute position information (based on index  
13 signals) to be obtained with a smaller relative error than in conventional sys-  
14 tems which used different sensors or encoder marks of different shape or size  
15 to distinguish between incremental and index markings.

16 All publications and existing systems mentioned in this specification are  
17 herein incorporated by reference.

18 Although certain methods and products constructed in accordance with  
19 the teachings of the invention have been described herein, the scope of cov-  
20 erage of this patent is not limited thereto. On the contrary, this patent covers  
21 all embodiments of the teachings of the invention fairly falling within the scope  
22 of the appended claims either literally or under the doctrine of equivalents.